

Optimizing trauma system design

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Optimizing Trauma System Design: The GEOS (“Geospatial Evaluation of Systems of Trauma Care”) Approach

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ABSTRACT

Background

Trauma systems have been shown to reduce death and disability from injury, but must be appropriately configured. A systematic approach to trauma system design can help to maximise geospatial effectiveness, and reassure stakeholders that the best configuration has been chosen.

Methods

This article describes the GEOS methodology, a mathematical modelling of a population-based dataset, which aims to derive geospatially optimised trauma system configurations for a geographically defined setting. GEOS considers a region's spatial injury profile, and the available resources, and utilises a combination of travel time analysis and multi-objective optimisation. The methodology is described in general, and with regards to its application to our case study of Scotland.

Results

The primary outcome will be trauma system configuration.

Conclusions

GEOS will contribute to the design of a trauma system for Scotland. The methodology is flexible, and inherently transferable to other settings, and could also be used to provide assurance that the configuration of existing trauma systems is fit for purpose.

Key words

Wounds and injuries, health services research

INTRODUCTION

The provision of trauma care remains a major public health issue, in both developed and low/middle income countries,¹⁻³ because the personal and societal costs of injury and treatment are high. Trauma systems – integrated and coordinated systems of tiered care for trauma patients – have been shown to reduce death and disability from injury,⁴⁻⁶ but must be appropriately configured. The benefits of an inclusive trauma system – which incorporates all acute hospitals – are well recognised, but the evaluation of trauma care remains focused on clinical outcomes such as mortality, and individual measures of process, rather than the performance of the system as a whole.

Specialist trauma care has been shown to be cost-effective,⁷⁻⁹ but trauma systems require considerable resources – including verified trauma centres, staffed by trauma surgeons, and land-based as well as airborne emergency medical services – which are expensive, and must be assigned responsibly. The designation and siting of these resources determines the geospatial effectiveness of a trauma system, defined as the product of a region's spatial injury profile (which incorporates the location and severity of the incidents), and the location and capabilities of the receiving healthcare facilities and mobile components of the trauma system. A systematic approach to trauma system design can help to maximise geospatial effectiveness, and reassure stakeholders that the best configuration has been chosen.

There have been previous attempts at providing objective solutions to trauma system design and evaluation. The most sophisticated is the Trauma Resource Allocation Model for Ambulances and Hospitals (TRAMAH).^{10,11} However, this model has intrinsic limitations, and we have therefore devised a more comprehensive method of determining geospatially optimised trauma system configurations. The methodology has been termed “Geospatial Evaluation of Systems of Trauma Care” (GEOS), and is currently being used to inform on the design of a trauma system for Scotland,¹² but is generic, and translatable to other

settings. The aim of this article is to describe the GEOS methodology, its application to Scotland, and discuss its applicability to other settings.

Context: Trauma care in Scotland

Major trauma care in the United Kingdom has, historically, long lagged behind countries with similar health services.¹³ At present, Scotland does not have a trauma system, and patients are taken to the nearest hospital with an emergency department. Retrieved is the responsibility of the Scottish Ambulance Service (SAS), which is the sole provider of emergency medical care. Following a series of reports, the Scottish Government has now committed to establishing a national trauma system. Scotland has approximately 5.2 million inhabitants,¹⁴ which reside in an area of 78,387 km² (30,414 sq mi). The topology and demography of Scotland bears resemblance to parts of the United States and Canada, with a large proportion of the population concentrated in a small number of cities, and large areas which are classed as rural and remote. As a result, there are concerns that the conflicting aims of establishing high volume trauma centres, and maintaining acceptable access times, may be difficult to balance.^{15,16}

Terminology

The terms used to describe trauma centre capability in the UK differ from those used in North America:

Major trauma centre. A major trauma centre (MTC) is a specialist hospital responsible for providing a regional or supraregional service for patients with major trauma, from a geographically defined area, which exceeds its local catchment area. The equivalent North American designation would be a “level 1” or “level 2” trauma centre.¹⁷ Major trauma centres require a certain case volume to effect improvements in outcome.

Trauma unit. A trauma unit (TU) is a hospital which manages less severely injured patients, from its local catchment area. It is broadly equivalent to a North American “level 3” trauma centre.¹⁷ For the purpose of GEOS Scotland, the minimum capability of a trauma unit is

defined as the availability of emergency medicine, anaesthesiology, critical care medicine, and general and orthopaedic surgical services.

Local emergency hospital. A local emergency hospital is a hospital which usually only deals with relatively minor injuries. However, local emergency hospitals are part of an inclusive trauma system.

METHODS

Design

GEOS is the mathematical modelling of a population-based dataset, which aims to derive geospatially optimised trauma system configurations for a geographically defined setting. It is divided into four phases. Phase 1 comprises the collection of triage data. Phase 2 comprises the calculation of travel times. Phase 3 mathematically models all trauma system configurations. Phase 4 comprises the multi-objective optimisation to select the optimal system configuration. The phases are described in terms of their general concept, and their application to our case study of Scotland.

Phase 1: Triage

Concept

A tiered trauma system requires a pre-hospital decision regarding which level of facility patients should be taken to. Patient flow is based on triage, rather than retrospectively calculated injury severity scores. The limited predictive value of triage for severe injury is well recognised, and basing the modelling on decision-making permits an accurate analysis of the effects of overtriage and undertriage on centre volumes and transport facilities.

Application

At present, Scotland does not utilise any form of pre-hospital triage, and the GEOS Scotland study therefore incorporates a notional triage of all incidents involving trauma attended to by the Scottish Ambulance Services, which is the sole provider of emergency medical capability in Scotland. The triage is notional because it does not affect patient management, and current operational policies – principally, that patients will be taken to the nearest emergency department – will continue to be followed. GEOS Scotland utilises the Center for Disease Control's Field Triage Decision Scheme (FTDS), which is widely used, and forms the basis of triage protocols in many other settings.¹⁸ It consists of four steps:

Step one represents physiological criteria, step two anatomical (injury) criteria, step three includes mechanistic criteria, and step four contains special considerations. If these criteria are met, the patient is directed to a certain level of facility, as determined by the response algorithm.

Pre-hospital episodes in Scotland are electronically coded, by emergency medical service providers, using the MPDS system (Medical Priority Dispatch Systems, MPDS; Priority Dispatch Corporation, Salt Lake City, Utah, USA), which is used to provide an initial despatch code, as well as a final diagnostic code. When a final diagnostic code matches a list of trigger codes which relate to traumatic injury (see supplementary table 1), an additional screen containing the four steps of the FTDS appears on the vehicles' on-board computers, which have to be answered as "yes" or "no" (fig 1). Completion of these fields is mandatory.

Notional triage data will be collected for 12 months, to allow for seasonal variations. The answers to the triage questions are incorporated into the SAS's electronic patient record form dataset, which is transmitted electronically, from the vehicles' computers, to the SAS's headquarters. Anonymised study data, including the GPS-determined incident location, is then exported for further processing and analysis. The responses to the triage questions are entered into a response algorithm, which determines the triage category. The GEOS Scotland response algorithm (supplementary figure 1) emulates the FTDS scheme, with three possible outcomes: triage to major trauma centre care, trauma unit care, or local emergency hospital care. Paramedics and other providers completing the triage questions are not aware of the response algorithm, or the triage category allocated to each patient.

Phase 2: Drive-time and flight-time calculations

Concept

Phase 2 comprises the calculation of drive- and flight-times from every incident location, to every hospital which could potentially become a trauma centre. A map of Scotland, and the contender hospitals and current helicopter depots, is shown in figure 2. Drive-times are

based on the quickest route from incident locations to destination facilities. Drive times are not be calculated for incidents occurring on islands, partly because these calculations are difficult and prone to error (having to take into account ferry times, time of day, and time of departure), and because casualties injured in such locations would almost certainly be retrieved by helicopter. Flight times are based on straight-line distances between helicopter depots and incident locations, and incident locations and destination facilities, taking into account the time from call to skids-up, and average casualty loading times.

Application

Drive time calculations are performed by Mercator GeoSystems (Mercator GeoSystems, Sheffield, UK), a geospatial information services company, using custom software. The calculations take into consideration road type, time of day, day of week, and “blue light” (ambulance) vehicle speeds. The assumed speeds for each road type are based on values used in the logistic industry and adjusted, using a multiplier, by population density of the area through which each road passes. (See supplementary tables 2 and 3.) Scotland presently has three helicopter depots, with one helicopter each. The calculations are based on the cruising speed of a Eurocopter EC-145T2 aircraft (135 knots), and assume full night-flying capability.

Phase 3: Configuration modelling

Concept

Each hypothetical configuration of trauma system can be described in terms of the designation of the contender hospitals. Phase 3 will test each configuration, using a combination of the triage category determined during phase 1, and the travel times calculated in phase 2, resulting in the allocation of each patient to a hypothetical trauma centre. The effect of this allocation can be measured in terms of the predicted centre volumes, predicted travel times, and helicopter utilisation. The testing of the configurations requires a simulated decision, taking into account the drive and flight times. It also needs to take into consideration that higher level centres will act as lower level centres for their local

population. These decisions can be summarised in an allocation algorithm (outlined in fig 4), which relies on two threshold values. The first is the maximum acceptable time for a casualty to reach the preferred level of destination healthcare facility, by road. In most trauma systems, this time is set at 45 mins. Casualties who fail to meet this threshold should be considered for transport by air. The second threshold is the acceptable time for a casualty to reach the preferred level of destination healthcare facility by air. If this threshold cannot be met, casualties will need to be taken to a lower level facility than triaged to. The default value for this threshold is again set at 45 mins, but can also be adjusted to take into consideration advanced pre-hospital capability, which may extend patients' physiological tolerance.

The application of the algorithm to the dataset has been programmed using MATLAB[®] (Mathworks[®], Massachusetts, USA). Each configuration is characterised by a number of parameters, including centre volume (of all patients, and those triaged to specific categories of care; for each centre, and system as a whole), exceptions/ undertriage, travel time (all patients, and by triage category; for each centre, and system as a whole), and helicopter usage (for the system as a whole; for each of the depots; and for each centre).

Application

There are approximately 4 million possible combinations of trauma system in Scotland, the number being constrained by the fact that only four of the hospitals could become major trauma centres. The simulated decision algorithm is outlined in figure 4 and described in detail in supplementary figures 2 and 3.

Phase 4: Multi-objective optimisation

Concept

Selecting the optimal configuration of trauma system requires criteria which define an efficient and effective trauma system. The principal consideration in trauma system design is “time to definitive care”,^{17,19-22} which can be expressed mathematically as two conflicting objectives: (1) The minimisation of travel time; and (2) the minimisation of the number of

“exceptions”, or system-related undertriage (patients who had to be taken to a lower level facility than triaged to).

The resolution of problems with conflicting objectives is helped by evolutionary algorithm, a meta-heuristic optimisation algorithm inspired by biological evolution, to select a set of mathematically optimised solutions. The key to understanding the output of these algorithms is to recognise that there is no single solution that simultaneously optimises each objective, but that there exist a number of solutions, referred to as “Pareto-optimised”, where some of the values cannot be improved without impairing others. GEOS employs a popular multi-objective evolutionary algorithm, Non-dominated Sorting Genetic Algorithm II (NSGA-II).²³ In addition to objectives, we also incorporated constraints, which are used to condense the Pareto-optimised set of solutions. These constraints can be used to introduce system characteristics, such as a minimum volume of patients seen in a certain level of facility, or model restrictions on the availability of helicopters.

The NSGA-II based optimisation used by GEOS has also been programmed using MATLAB[®] (Mathworks[®], Massachusetts, USA). A detailed discussion of the computational aspects is outwith the scope of this article, and will be published separately.

Application

GEOS Scotland utilises four constraints:

1. Exceptions/system-related undertriage. In addition to being one of the optimisation objectives, a threshold level of acceptable system-related undertriage will also be used as a constraint. This level has been set at 25% of the total volume of severely injured patients encountered in Scotland per year. A system configuration which would result in a greater number of patients than this not reaching the level of care which they had been triaged to will not be considered further.
2. Major trauma centre volume threshold. The existence of a volume/outcome relationship in trauma care is well recognised, but the position of the inflection point at which improvements in mortality can be demonstrated is contentious, and activity volumes

ranging from 240 to 650 severely injured patients per year have been suggested.²⁴⁻²⁶ The beneficial effect of higher volumes is probably mediated by the presence of key organisational characteristics, which may not be justifiable at lower case volumes. GEOS Scotland will explore all three commonly quoted cut-offs (>250, >400, and >650 severely injured patients per year).

3. Inclusivity and proximity. Trauma units fulfill two different functions, depending on their location: In rural areas, TUs will be the only facilities available, may have low volume, but will occasionally have to deal with triaged-to-MTC cases which cannot be taken to an MTC in time. In urban areas, in contrast, TUs will be associated with MTCs, which will admit patients who have been triaged to MTC care.¹⁷ In large conurbations, there may be several hospitals, in close proximity, which fulfill the criteria for a trauma unit, introducing a degree of redundancy if all were designated as trauma units. GEOS Scotland will consider both maximally inclusive configurations (in which trauma unit capability is maximally distributed), and less inclusive (proximity constrained) configurations, which will be defined as not having more than one trauma unit within 45 mins drive time of each other. This criterion limits the number of trauma units without reliance on a volume threshold, for which there is no evidence, although the existence of a volume/outcome relationship probably extends to outcomes other than mortality. It also acknowledges the different roles of TUs in rural and urban settings, without explicitly defining them. In effect, this permits systems to have both low-volume rural trauma units, and high-volume urban trauma units, which concentrate non-MTC trauma activity. The 45 min cut-off is the same as the maximum acceptable time for a casualty to reach the preferred level of destination healthcare.

4. Helicopter availability. This constraint is based on the recognition that helicopter retrieval is costly, and that helicopters are a finite resource. The GEOS Scotland modelling will initially be based on the existing fleet configuration, comprising one helicopter at each of the three depots. Sensitivity analyses will consider a limited expansion of the fleet, up to

two airframes per depot. The maximum realistic number of missions which can be flown was set at seven per 24 hours.

Sensitivity and vulnerability analyses

A number of planned sensitivity analyses will determine the effect of varying the assumptions – regarding acceptable travel times thresholds, MTC volume thresholds, helicopter availability, TU proximity – pertaining to the configuration of the trauma system. GEOS will also include a number of vulnerability analyses, which will evaluate the performance of a selected number of configurations in response to system stressors. The model will be validated with bootstrapping, by resampling and reanalysing the dataset to determine the effect of varying the spatial injury profile on system configuration.

DISCUSSION

A highly performing trauma system has many components and processes, which cannot be reduced to a mathematical equation alone. Nevertheless, geospatial evaluation can help with the design of such a system, and the evaluation of existing systems.

The methodology described here provides a comprehensive means of modelling, and comparing, different configurations. Although complex, the GEOS methodology is relatively intuitive, because it is iterative, and it overcomes several of the limitations of the TRAMAH model.^{10,11} TRAMAH uses place of residence as a proxy for incident location, and relies on ZIP code centroids, rather than more precise geocoding, and thus lacks geographical granularity. Travel time calculations in GEOS, in contrast, are based on the location of the incident. TRAMAH furthermore defines the need for trauma centre care in terms of injury severity scores, rather than triage. As a result, TRAMAH cannot accurately model patient flow, or the effect of trauma centre designation on hospital volume. Lastly, TRAMAH does not stratify trauma centers, and does not take into consideration center volume thresholds or aeromedical capacity constraints, whereas GEOS stratifies centres by capability and takes into consideration capacity issues, thus modelling the trauma system as a whole.

However, GEOS also has limitations. Triage decisions may not be routinely recorded by Emergency Medical Services, and although the collection of such data can be set up – as we have demonstrated in Scotland – this may be difficult when multiple providers are involved. GEOS relies on the positive predictive value of triage for determining severe injury, as measured by injury severity score, to determine centre volume thresholds and volumes. A regionally derived value is preferable to one derived from the literature, to account for variation in practice, and such a study is being performed concurrently in Scotland. Lastly, GEOS is computationally complex, and requires substantial processing power.

Despite these limitations, GEOS represents an advance in trauma system modelling and design. The methodology is flexible, although presently still requires a programmer to modify, and inherently transferable to other settings, by adapting the centre stratification and volume thresholds, travel time thresholds, and multi-objective optimisation constraints. The methodology can also be used to provide assurance that the configuration of existing trauma systems is fit for purpose, by comparing the geospatial effectiveness of current configurations with “ideal” configurations, as determined by GEOS.

The data collection for GEOS Scotland will be completed in June 2014. The results will provide crucial data to inform the development of Scotland’s trauma system.

FIGURES

Fig 1. Screenshot of Scottish Ambulance Service's triage screen, on vehicle computer

©2009	Incident No:	0123456	Date:	30/01/13	Time:	12:03
Back	Keypad	GEOS Triage Tool			Incident message	Lock workstation

GEOS Q1: EVALUATE VITAL SIGNS AND LEVEL OF CONSCIOUSNESS Does the patient have, or did the patient have, any of the following, at any time? <ul style="list-style-type: none"> Glasgow Coma Scale <14 Systolic blood pressure <90 Respiratory rate <10 or >29 (or <20 in infants less than one year) 	GEOS Q2: ASSESS ANATOMY OF INJURY Are any of the following present? <ul style="list-style-type: none"> Penetrating injuries to head, neck, torso, or extremities proximal to elbow or knee Flail chest Two or more proximal long-bone fractures Crushed, degloved, or mangled extremity Traumatic amputation proximal to wrist or ankle Pelvic fracture Open or depressed skull fracture
<input type="button" value="Yes"/> <input checked="" type="button" value="No"/>	<input type="button" value="Yes"/> <input type="button" value="No"/>

GEOS Q3: ASSESS MECHANISM OF INJURY/EVIDENCE OF HIGH-ENERGY IMPACT Did the patient suffer any of the following?? Falls <ul style="list-style-type: none"> Adults: >20 feet (one storey is approx 10 feet) Children: >10 feet or 2-3 times the height of the child High-risk automobile crash <ul style="list-style-type: none"> Intrusion: >12 inches at occupant site; >18 inches any site Ejection (partial or complete) from vehicle 	GEOS Q4: ASSESS SPECIAL PATIENT OR SYSTEM CONSIDERATIONS Are any of the following present? <ul style="list-style-type: none"> Age >55 years Anticoagulation or bleeding disorder Burns (with trauma mechanism) Time-sensitive extremity injury End-stage renal disease requiring dialysis Pregnancy >20 weeks
<input checked="" type="button" value="Yes"/> <input type="button" value="No"/>	<input type="button" value="Yes"/> <input type="button" value="No"/>

Fig 2. Map of Scotland, showing location of contender hospitals and helicopter depot locations [to follow]

Fig 3. Allocation algorithm, in general

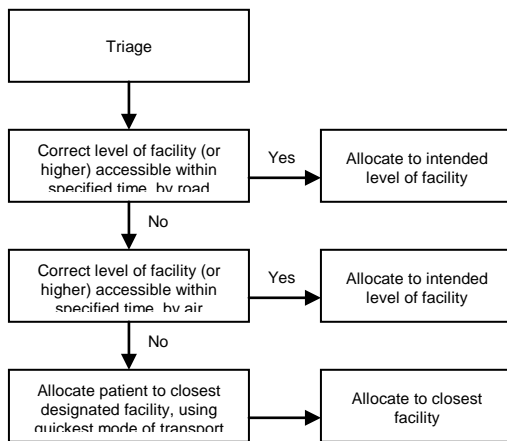
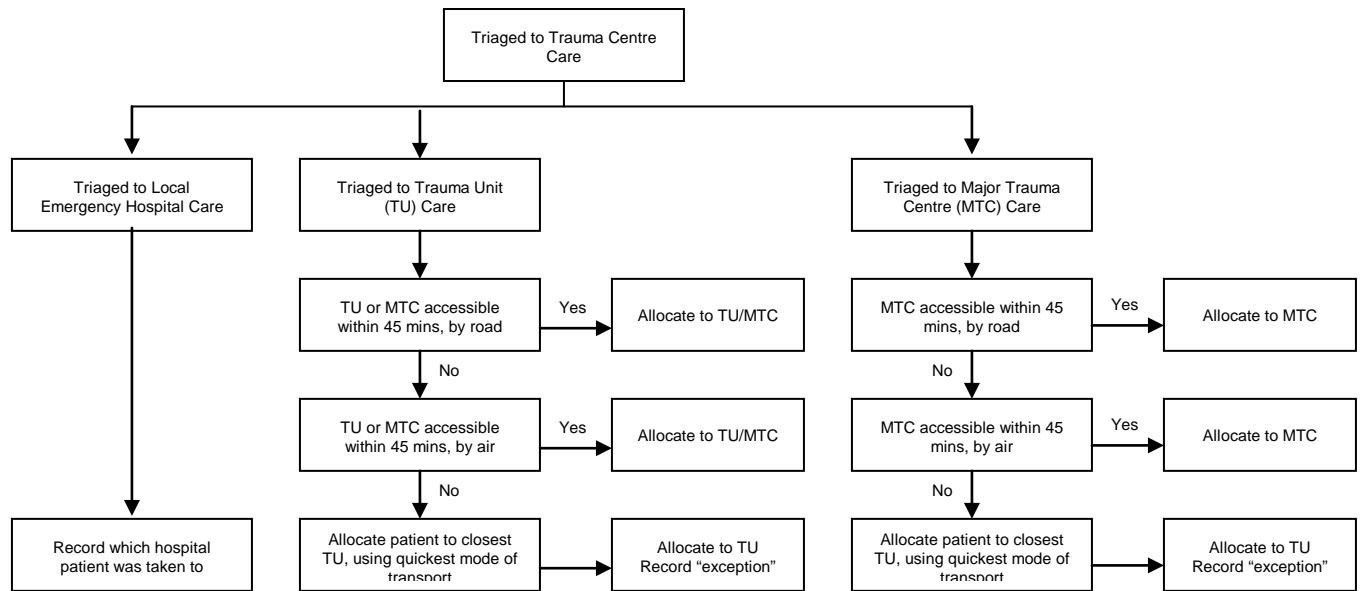


Fig 4. Allocation algorithm, as applied to Scotland



SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE 1. MPDS trigger codes.

Code	Description
CARD 03: ANIMAL BITES/ATTACKS	
03D01	Animal Bites, Unconscious or arrest
03D02	Animal Bites, Not alert
03D03	Animal Bites, Chest or neck injury (with difficulty breathing)
03D04	Animal Bites, Multiple victims
03D05	Animal Bites, Large animal
03D06	Animal Bites, Exotic animal
03D07	Animal Bites, Attack or multiple animals
03B01	Animal Bites, Possibly dangerous body area
03B02	Animal Bites, Serious haemorrhage
03B03	Animal Bites, Unknown status/other codes n/a
03A01	Animal Bites, Not dangerous, proximal body area
03O01	Animal Bites, Not dangerous, distal body area
03O02	Animal Bites, Non recent (>6hrs) injuries without priority symptoms
03O03	Animal Bites, Superficial bites
CARD 04: ASSAULT/SEXUAL ASSAULT	
04D01	Assault, Unconscious or arrest
04D02	Assault, Not Alert
04D03	Assault, Chest or neck injury, difficulty breathing
04D04	Assault, Multiple victims
04B01	Assault, Possibly dangerous body area
04B02	Assault, Serious Haemorrhage
04B03	Assault, Unknown status/other codes n/a
04A01	Assault, Not dangerous proximal body area
04A02	Assault, Non-Recent Injury = >6hrs except Distal Body Area
04O01	Assault, Not dangerous distal body area
04O02	Assault, Non recent (>6hrs) injuries to distal body area without priority symptoms
CARD 07: BURNS/EXPLOSION/SCALD	
07D01	Burns/Explosion, Multiple victims
07D02	Burns/Explosion, Unconscious or arrest

07D03	Burns/Explosion, Not alert
07D04	Burns/Explosion, Difficulty speaking between breaths
07C01	Building fire with persons reported inside
07C02	Burns/Explosion, Difficulty breathing
07C03	Burns/Explosion, = > 18% Body Area
07C04	Significant facial burns
07B01	Blast injuries without priority symptoms
07B02	Burns/Explosion, unknown status, other codes n/a
07A01	Burns <18% body area
07O01	Sunburn or minor burn (hand-size)

CARD 09: CARDIAC/RESPIRATORY ARREST/DEATH

09E03	Cardiac/Resp Arrest, Hanging
09E04	Cardiac/Resp Arrest, Strangulation
09E05	Cardiac/Resp Arrest, Suffocation
09B01b	Obvious or expected death unquestionable, decapitation
09B01c	Obvious or expected death unquestionable, decomposition
09B01d	Obvious or expected death unquestionable, incineration
09B01f	Obvious or expected death unquestionable, severe injuries incompatible with life

CARD 15: ELECTROCUTION/LIGHTNING

15E01	Electrocution/Lightning, Not breathing/ineffective breathing
15D01	Electrocution/Lightning, Unconscious
15D02	Electrocution/Lightning, Not disconnected from power
15D03	Electrocution/Lightning, Power not off or hazard present
15D04	Electrocution/Lightning, Extreme fall (>30ft/10m)
15D05	Electrocution/Lightning, Long fall
15D06	Electrocution/Lightning, Not alert
15D07	Electrocution/Lightning, Abnormal breathing
15D08	Electrocution/Lightning, Unknown status/other codes n/a
15C01	Electrocution/Lightning, Alert and breathing normally

CARD 16: EYE PROBLEMS/INJURIES

16D01	Eye Problems/Injury, Not alert
16B01	Eye Problems/Injury, Severe eye injuries
16A01	Eye Problems/Injury, Moderate Eye Injuries
16O01	Eye Problems/Injury, Minor Eye Injuries

CARD 17: FALLS

17D01	Falls, Extreme fall
17D02	Falls, Unconscious or arrest
17D03	Falls, Not alert
17D04	Falls, Chest or neck injury with difficulty breathing
17D05	Falls, Long fall
17B01	Falls, Possibly Dangerous Area
17B02	Falls, Serious Haemorrhage
17B03	Falls, Unknown Problem, other codes n/a
17A01	Falls, Not dangerous proximal body area
17A02	Falls, Non-recent (>6hrs) injuries except distal body area (without priority symptoms)
17O01	Falls, Non dangerous distal body area
17O02	Falls, Non-recent (>6hrs) injuries to distal body area (without priority symptoms)

CARD 21: HAEMORRHAGE/LACERATION

21D01	Haemorrhage/Laceration, Unconscious or arrest
21D02	Haemorrhage/Laceration, Not alert
21D03	Haemorrhage/Laceration, Dangerous Haemorrhage
21D04	Haemorrhage/Laceration, Abnormal breathing
21C01	Haemorrhage/Laceration, Haemorrhage through tubes
21C02	Haemorrhage/Laceration, Haemorrhage through dialysis fistula
21B01	Haemorrhage/Laceration, Possibly dangerous haemorrhage
21B02	Haemorrhage/Laceration, Serious haemorrhage
21B03	Haemorrhage/Laceration, Bleeding disorder
21B04	Haemorrhage/Laceration, Blood thinners
21A01	Haemorrhage/Laceration, Not dangerous haemorrhage
21A02	Haemorrhage/Laceration, Nose-bleed (>35yrs or <35yrs with serious haemorrhage)
21O01	Haemorrhage/Laceration, Minor haemorrhage
21O02	Haemorrhage/Laceration, Nose-bleed <35 yrs
21O03	Haemorrhage/Laceration, Non-bleeding laceration

CARD 22: INACCESSIBLE INCIDENT/NON-VEHICULAR ENTRAPMENT

22D01	Inaccessible In incident, Mechanical/machinery entrapment
22D02	Inaccessible Incident, Trench collapse
22D03	Inaccessible Incident, Structure collapse
22D04	Inaccessible Inc incident, Confined space entrapment
22D05	Inaccessible Incident, Inaccessible terrain
22D06	Inaccessible Incident, Mudslide/avalanche

- 22B01 Inaccessible Incident, No longer trapped (unknown injuries)
- 22B02 Inaccessible Incident, Peripheral entrapment only
- 22B03 Inaccessible Incident, Unknown status, other codes n/a
- 22A01 Inaccessible Incident, No longer trapped, no injuries

CARD 25: PSYCHIATRIC/ABNORMAL BEHAVIOUR/SUICIDE ATTEMPT

- 25D02 Psychiatric, Dangerous haemorrhage
- 25B01 Psychiatric, Serious haemorrhage
- 25B02 Psychiatric, Non-serious or minor haemorrhage
- 25B05 Psychiatric, Near Hanging, Strangulation or Suffocation (Alert)

CARD 27: STAB/GUN/PENETRATING TRAUMA

- 27D01 Stab/Gun/Penetrating, Unconscious or arrest
- 27D02 Stab/Gun/Penetrating, Not alert
- 27D03 Stab/Gun/Penetrating, Central wounds
- 27D04 Stab/Gun/Penetrating, Multiple wounds
- 27D05 Stab/Gun/Penetrating, Multiple victims
- 27B01 Stab/Gun/Penetrating, Non-recent (>6hrs) single central wound
- 27B02 Stab/Gun/Penetrating, Known single peripheral wound
- 27B03 Stab/Gun/Penetrating, Serious haemorrhage
- 27B04 Stab/Gun/Penetrating, Unknown status, other codes n/a
- 27B05 Stab/Gun/Penetrating, Obvious death (explosive shot to head)
- 27A01 Stab/Gun/Penetrating, Non-recent (>6hrs) peripheral wounds (without priority sy)

CARD 29: TRAFFIC/TRANSPORT ACCIDENT

- 29D01a Traffic/Transport Accident, Multiple response incident, aircraft
- 29D01b Traffic/Transport Accident, Multiple response incident, bus
- 29D01c Traffic/Transport Accident, Multiple response incident, below ground (eg subway, tube)
- 29D01d Traffic/Transport Accident, Multiple response incident, above ground (train, tram)
- 29D01e Traffic/Transport Accident, Multiple response incident, watercraft
- 29D01f Traffic/Transport Accident, Multiple response incident, multi-vehicle (>10 vehicles)
- 29D02k Traffic/Transport Accident, High mechanism, all-terrain/snowmobile/quad
- 29D02l Traffic/Transport Accident, High mechanism, vehicle vs. bike, motorbike
- 29D02m Traffic/Transport Accident, High mechanism, vehicle vs. pedestrian
- 29D02n Traffic/Transport Accident, High mechanism, ejection
- 29D02o Traffic/Transport Accident, High mechanism, personal watercraft, jet ski
- 29D02p Traffic/Transport Accident, High mechanism, rollover
- 29D02q Traffic/Transport Accident, High mechanism, vehicle off bridge, height involved

29D02r	Traffic/Transport Accident, High mechanism, possible death at scene
29D02s	Traffic/Transport Accident, High mechanism, sinking vehicle
29D03	Traffic/Transport Accident, Hazchem
29D04	Traffic/Transport Accident, Trapped victim
29D05	Traffic/Transport Accident, Not alert
29B01	Traffic/Transport Accident, Injuries
29B02	Traffic/Transport Accident, Serious haemorrhage
29B03	Traffic/Transport Accident, Other hazards
29B04	Traffic/Transport Accident, Unknown status, other codes n/a
29A01	Traffic/Transport Accident, 1st party caller with injury to not dangerous prox body area
29O01	Traffic/Transport Accident, no injuries (confirmed)
29O02	Traffic/Transport Accident, 1st party caller with injury to not dangerous distal body area

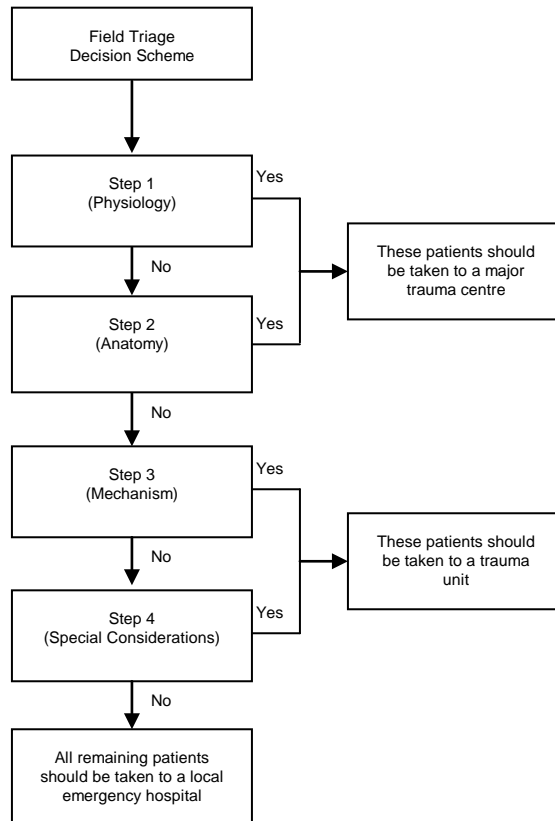
CARD30: TRAUMATIC INJURIES (SPECIFIC)

30D01	Traumatic Injuries, Unconscious or arrest
30D02	Traumatic Injuries, Not alert
30D03	Traumatic Injuries, Chest or neck injury, difficulty breathing
30B01	Traumatic Injuries, Possibly dangerous body area
30B02	Traumatic Injuries, Serious haemorrhage
30A01	Traumatic Injuries, Not dangerous proximal body area
30A02	Traumatic Injuries, Non-recent (>6hrs) injuries except distal (without priority sy)
30O01	Traumatic Injuries, Not dangerous distal body area
30O02	Traumatic Injuries, Non-recent (>6hrs) injuries to distal body area (without priority sy)
30O03	Traumatic Injuries, Splinters (<1"/2.5cm)

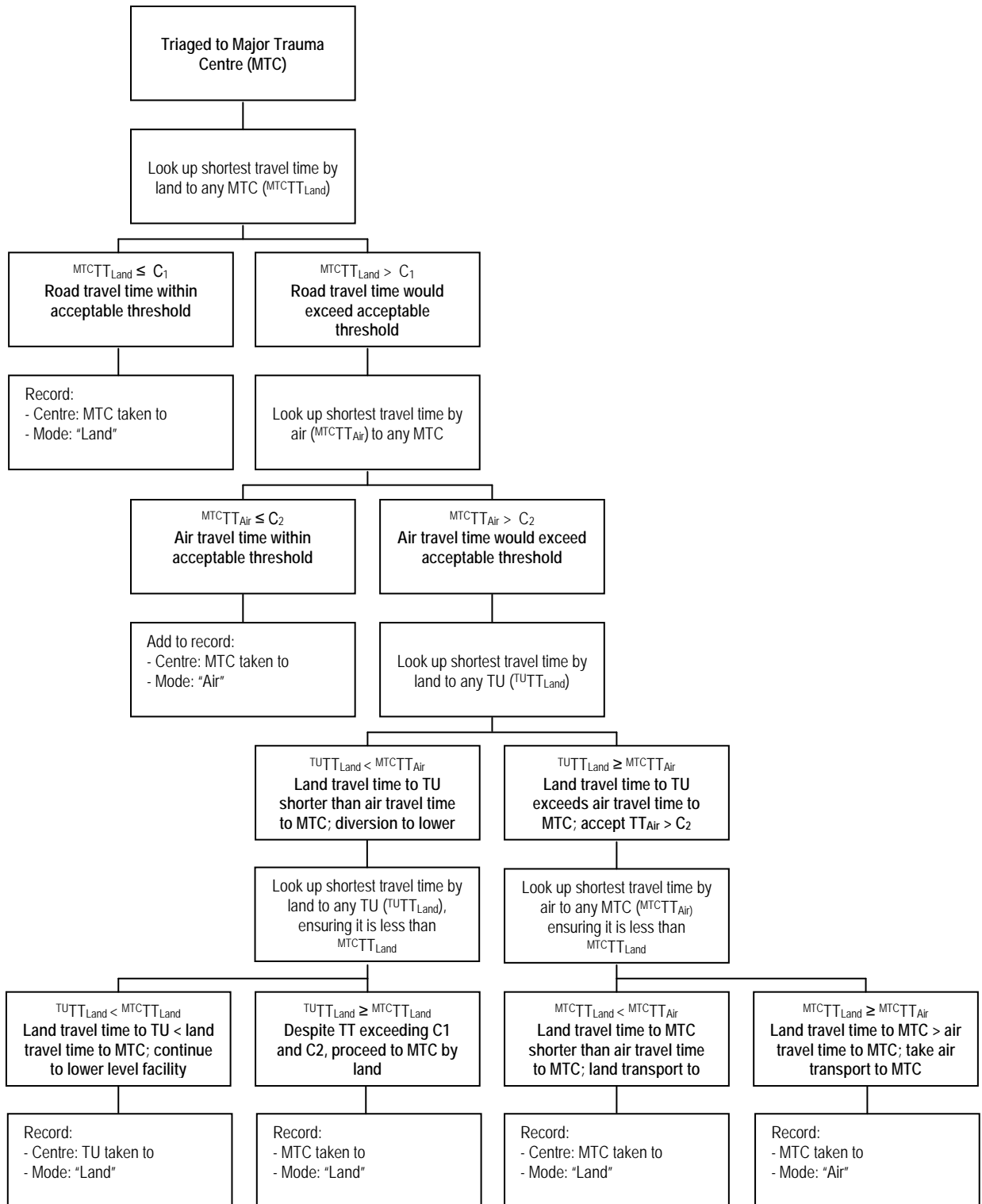
SUPPLEMENTARY TABLE 2: Blue light drive times		
Road Type	Off-Peak (mph)	Peak (mph)
Motorway	80	70
Primary road (dual carriageway)	70	55
Primary road	60	45
Primary road (narrow)	50	40
Primary road (trunk)	50	40
A road (dual carriageway)	55	45
A road	40	35
A road (narrow)	35	30
A road (trunk)	35	30
B road	35	25
B road (narrow)	30	25
Minor road	30	25

SUPPLEMENTARY TABLE 3: Multipliers to adjust for degree of rurality		
Urban-ness/rurality	Off-Peak multiplier	Peak multiplier
1	1.60	1.80
2	1.40	1.65
3	1.25	1.45
4	1.15	1.25
0	1.00	1.00

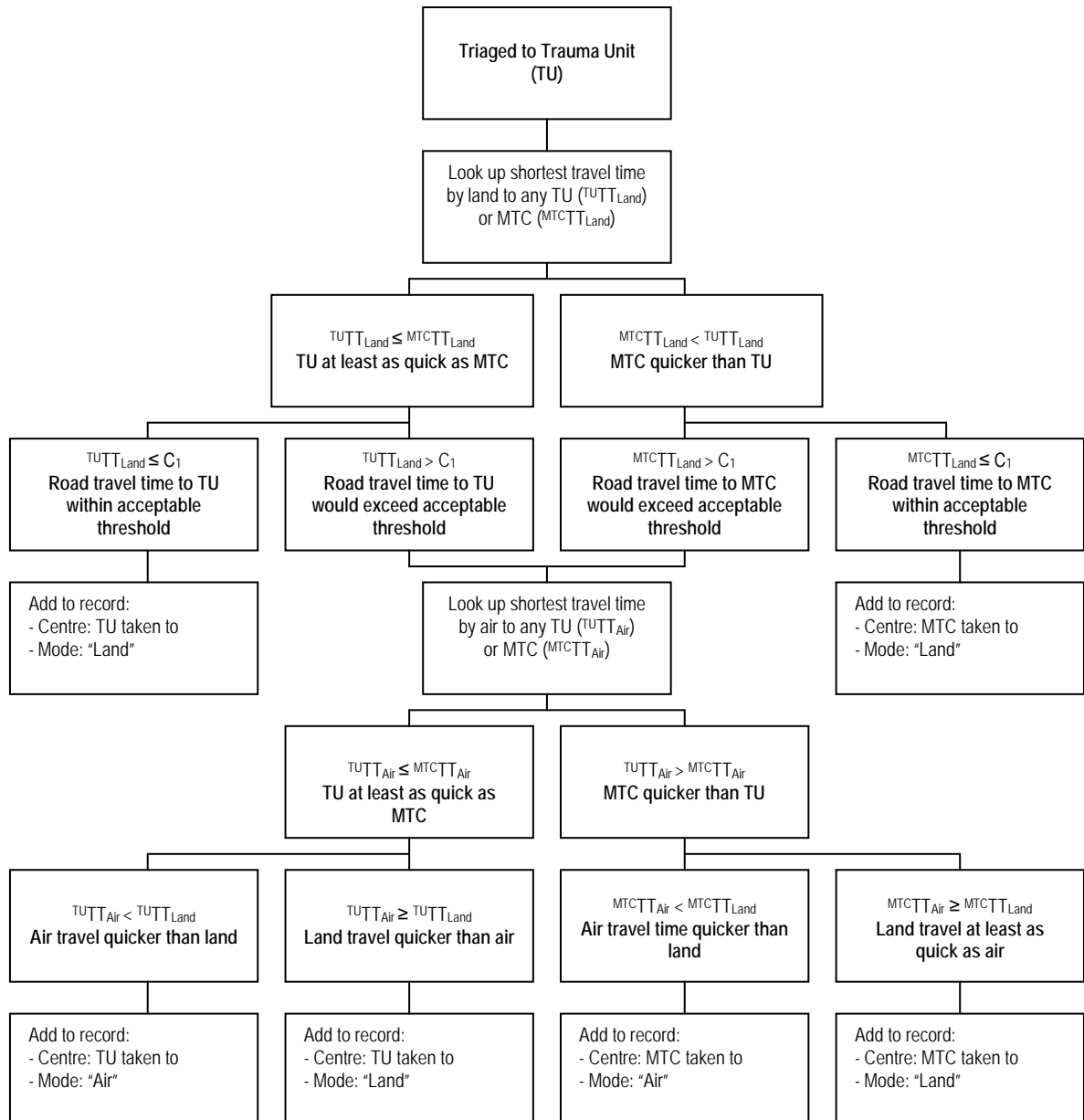
Supplementary Figure 1: GEOS Scotland response algorithm



Supplementary figure 2: Detailed allocation algorithm, for patients allocated to MTC care



Supplementary figure 3: Detailed allocation algorithm, for patients triaged to TU care



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I will sort out reference-manager-typo prior to submission.

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